Harmonic Reduction Using SVPWM and Active Harmonic Filter and their comparative analysis

A thesis submitted in partial fulfillment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

in

ELECTRICAL ENGINEERING

Submitted by

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CERTIFICATE

This is to certify that **Adiba Asmat (111EE0193)** and **Prajna Pallabee Ray (111EE0227),** of 8th semester Electrical Engineering have accomplished the final year B.Tech Project on "**Harmonic Reduction Using SVPWM and Active Harmonic Filter and their comparative analysis**" reasonably.

This project is submitted in partial fulfillment towards the Bachelor's degree in Electrical Engineering as prescribed by the institute during the year 2014-2015.

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ABSTRACT

A large amount of harmonics is produced by the increasing practice of electronic equipments in energy distribution systems. It is owing to the nonsinusoidal currents expended in nonlinear loads. Non-linear loads include :

- diode-rectifiers,
- thyristor converters,
- variable speed drives,
- furnaces,
- computer energy supplies,
- UPSs, etc.

Even though such devices are cost-effective, adaptable and power efficient, these possess the disadvantage of worsening the quality of power by generating harmonic currents as well as exhausting unnecessary reactive power. This phenomenon may lead to a lot of tribulations: e.g. resonance, undue neural currents, reduced power factor and much more.

A dynamic role is played by Pulse Width Modulation Inverters in the area revolving around power electronics. PWM adjustable speed drives find numerous applications in several new industrial presentations requiring excellent performance. In recent times, expansions in the field of power electronics have given birth to a wide progress in such systems. Consequently, diverse circuit configurations, for example multilevel inverters are gaining a lot of popularity as well as creaing a substantial interest.

The most prevalent pulse width modulation scheme which is conceivably the most efficient among other PWM techniques is Space Vector Modulated PWM (SVPWM) since it manages to produce high voltages accompanied with less total harmonic distortion as well as toils splendidly field oriented structures to achieve motor control. Space Vector PWM (SVPWM) is gaining a lot of importance owing to its relaxed digital realization and healthier dc bus operation. Elimination of a number of small order harmonics by implementing an appropriate harmonic elimination methodology can lead to an excellent quality spectrum of output.

The emphasis of the project has been laid on induction motor on which the two methods of harmonic elimination technique has been executed – SVPWM and shunt active filter. The deliberation of a prototype of 3-phase voltage-source inverter centered on the concept of space vector can be easily found in this study. Simulation results have been shown clearly in the study which have been acquired with the help of MATLAB/Simulink to strengthen the claims we have made in this study. Finally, a comparative study has been made between the two methodologies discussed in order to decide which one is the better method to eliminate harmonics.

CHAPTER 1

INTRODUCTION

2.1 LITERATURE REVIEW

- “The electromagnetic wave possesses a harmonic motion whose frequency component comes out to be the integral multiple of base frequency, which is very popularly known as harmonic” [4] .

- Shunt active power filters (APF) dominate over passive filters in the quality of counteracting harmonic distortion as well as destabilization produced by harmonics generation [1].

- For obtaining mutable voltage and at the same time frequency supply for alternating current drives, 3-phase Voltage Source Inverters (VSI) are usually brought into application. Numerous PWM techniques have been developed in the past for the achievement of mutable voltage along with frequency supply. Renowned ones among them are carrier-based sinusoidal PWM and space vector modulation (SVM) PWM [1].

- The output voltage per phase for a sinusoidal PWM based three phase converter is limited to 0.5 Vdc (peak value), the line-to-line RMS (root mean square) voltage is 0.612Vd. SVM is another direct digital PWM technique proposed in 1982 [2]. It has become a basic power processing technique in three-phase converters [3].

- SVM based converter can have a higher output voltage output at 0.707Vdc (Line-to-line, RMS). Therefore, SVM improves ac voltage by 15.15% [4]. Furthermore, SVM algorithms can be easily implemented using digital controllers [5]. A model of SVM on MATLAB/Simulink has been developed [1].

- A perfect way that comes out to unravel all the issues of harmonics is the suitable usage of filters in power system. Setting up a filter in the power system can reduce harmonics up to a considerable level created by nonlinear loads [6].

- Active filters minimize the effect of harmonic current by using the active power conditions to produce equal amplitudes of opposite phase there by canceling the harmonics that are caused in the nonlinear components and replace the current wave from the nonlinear load [4].

2.2 MOTIVATION

Harmonic generation is the undesirable outcome of industrial electronic devices and non-linear loads. The output waveform comprises of numerous diverse waveforms holding diverse frequencies since the current which is taken from supply is no more purely sinusoidal.

Because of the rigorous utilization of power converters and similar nonlinear loads in different sectors for different purposes, cumulative decline in the voltage waveforms as well as current waveforms has been witnessed. The current carried by a nonlinear load can never be free from harmonics. Distortion of load voltage is the adverse outcome of voltage dropping non-linearly which is caused by none other than the line current harmonics. The current carried by the linear load becoming non-sinusoidal is caused by the distortion in load voltage.

The resulting current is found to be distorted owing to the fact that current and voltage don't hold linear relationship in the case of non-linear load rather we can say that Ohm's law gets violated in this case, when a pure sine wave supply is provided to a nonlinear resistor. A slight surge in a voltage can even make the current to rise up to its twice and take a completely altered wave-shape.

Equipments responsible for harmonics :

Harmonics are nothing but the offshoots of contemporary amenities and automated equipments and they are essentially known as non-linear loads.

Specimen of these loads can be listed as :

- Computers and PCs,
- Printers and equipments with SMPS,
- Battery Chargers
- Controlled Rectifiers,
- Traction Equipment ,
- UPS systems
- Fan Regulators
- SCADA systems
- PLC and DCS

The polluted power supply which is responsible for reducing power factor and augmenting electrical losses, which in turn lead to untimely failure and improper working of the machine are the undesirable outcomes of harmonics.

The harmonic currents produce unfavorable influence on the power system.

For example :

- overheating,
- sensitivity of control gets perturbed,
- capacitor blowing,
- motor vibration,
- undesirable neutral currents,
- grid resonance,and
- reduced power factor.

The simplest approach to remove harmonics in current is direct application of passive LC filters. However, they possess several limitations such as huge size, tuning problems, resonance and fixed compensation characteristics.

With a view of compensating the biased currents the APF introduces currents in the system which are equal in magnitude but opposite in polarity with the harmonic components.

Total harmonic distortion can be defined as the ratio of the RMS value of the sum of all harmonic components and the RMS value of the fundamental component. This holds true for current as well as voltage.

On account of the problems generated by harmonics development, the quality of power extended to the consumers is a topic of adequate apprehension.

There exists a classification of those problems which are :

- Instantaneous problems
- Long-term problems

- ✓ The first category of problems i.e. instantaneous problems are linked with interferences, breakdown or functioning deterioration of the equipments.
- ✓ The second category of problems i.e. long-term problems are linked with thermal disturbances and remain in association with surplus losses and overheating, leading to a deterioration in the average lifetime of rotating machines, capacitors and transformers.

With the purpose of enhancing efficiency along with the broadening of generation for the consumers, or simultaneity to be maintained in a building where the households and industrial consumers dwell together, the innovative equipments in addition to some facilities are introduced for the purpose of enriching the coziness in civil construction.

The repurcussion of the latest energy sources which hold the merit of transforming a consumer into a power supplier should be noticed. Nevertheless, such alterations have brought about the advent of unwanted occurences in a power system, interpreting some unwelcome encounters which need to be be answered by the designers and the managers of the power system who are nobody but the engineers and scientists of the nation.

With the motive of guaranteeing the efficient utilization of electricity, amongst all the initiatives needed, the necessity of adapting with the prevailing electrical network and the introduction of latest innovative and progressive schemes of control, censoring and management, must be mentioned.

CHAPTER 2

SPACE VECTOR PULSE WIDTH MODULATION (SVPWM)

Space Vector Pulse Width Modulation (SVPWM) :

- A noteworthy role is played by Pulse Width Modulation (PWM) inverters concerning power electronics.

- The most prevalent pulse width modulation scheme which is conceivably the most efficient one among all other PWM techniques is Space Vector Modulated PWM (SVPWM) since it manages to produce high voltages accompanied with less total harmonic distortion as well as toils splendidly field oriented structures to achieve motor control.

- Elimination of a number of small order harmonics by implementing an appropriate harmonic elimination methodology can lead to an excellent quality spectrum of output.

- SVPWM signifies an exceptional switching scheme of six semiconductor switches of a 3-phase converter.

- SVPWM has turned out to be a standard and prevalent PWM technique in some purposes like induction motor and synchronous motor control for 3-phase voltage-source inverters

- SVPWM is well known for its efficient modulation technique as compared to other methods as it causes reduced harmonic distortion in output voltage as well as current which is applied to the ac motor phases. This in turn makes the most efficient use of the supply voltage when compared to other modulation schemes.

- The switching frequency can be regulated with great ease in the case of SVPWM as it enables a steady unvarying switching frequency.

- Even though, SVPWM is more complex and intricate than other methods of harmonics elimination, it may be executed with great ease involving recent digital signal processing based control mechanism.

- For employing pulse width modulation (PWM) on three phase switching converters, space vector modulation (SVM) is an effective method to be applied. Operation of converter hardware for smooth working is increased with the help of SVM.

- On comparing with sinusoidal PWM, it is observed that SVM can accomplish a higher AC voltage level (15% more in magnitude).In this work, we have developed a SVM models in Matlab/Simulink, which is a most common and well known in the field of power system dynamic research. In order to illustrate the principles of SVM based sinusoidal waveform synthesis theory of space vector has been clearly explained.

The three unique inputs of this include :

(i) A saw tooth triangular waveform is used to produce repeating switching period for digital control

(ii) A method to incorporate blocks with different sampling rates is employed to generate SVM pulses

(iii) Matlab / Simulink model is developed.

The models that are developed are very useful to extend detailed SVM enabled power converters in the study of power system.

ANALYSIS OF TWO LEVEL SVPWM INVERTER

- The technique of SVPWM initially came into existence as a vector approach to Pulse Width Modulation (PWM) for 3-phase inverters.

- This technique is well-versed in generating sinusoidal waves that supplies higher voltages with less total harmonic distortion with sufficient sophistication.

- The classical prototype model of a characteristic three-phase two level voltage source PWM inverter has been indicated in Figure.1.
  - S1-S6: These are the six switches which are responsible for shaping the output, regulated by the switching variables a, a’, b, b’, c and c’.
  - The corresponding lower transistor is switched or, we can say a’, b’ or c’ become zero, when the upper transistor is switched on i.e. when a, b or c is 1.

- Hence, the output voltage can be determined by the on and off states of the transistors.

- SVPWM scheme involves 180^0 conduction for the generation of gate signals. In case, two switches (one upper and one lower) conduct simultaneously in such a way that the output voltage is ± Vs, the switch state is 1. In case, the two switches are off simultaneously, the switch state is 0.

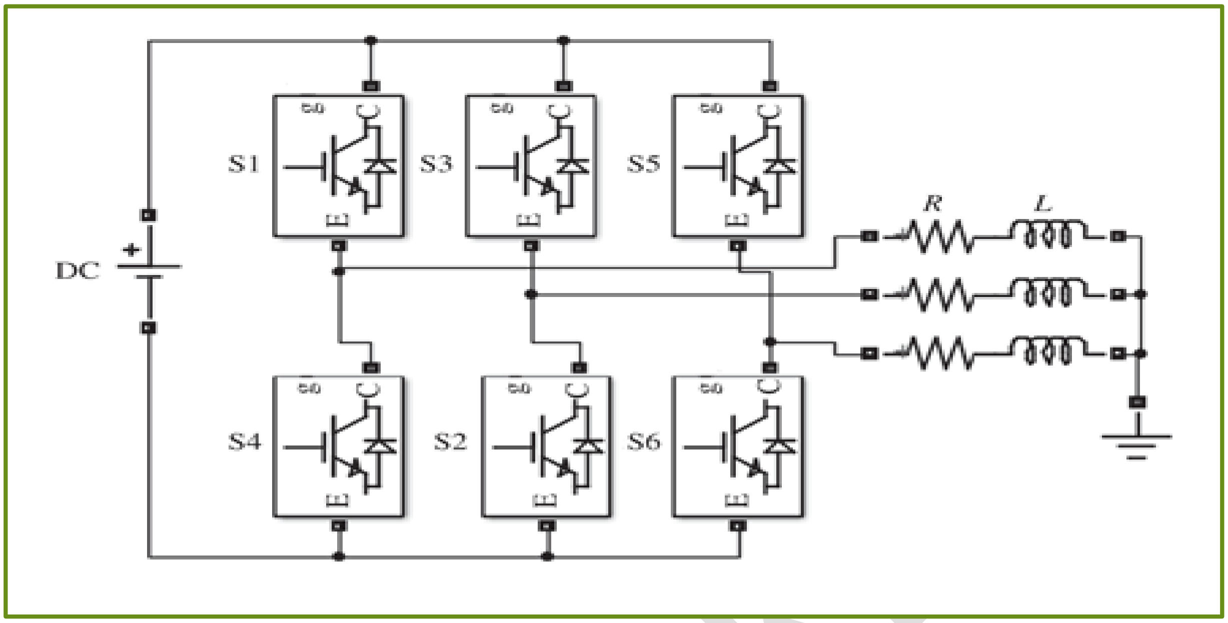


Figure. 1. 3- phase voltage source inverter (VSI)

- The figure shows the space vector diagram of a three level inverter which can be thought of composed of six hexagons.

- The space vector diagram of a 3-level inverter which is centred on the six high points of the hexagon, is constituted by six hexagons.

- Two points need to be followed in order to get the simplified space vector diagram of a 3-level inverter :
  - ➢ One hexagon needs to be chosen amongst the six hexagons from the position of a reference voltage.
  - ➢ Then, the amount of the center voltage of the selected hexagon has to be subtracted from the previous reference voltage.

- 5-level space vector plane gets transformed to the 3-level space vector plane with the above specified two steps.

- The space vector diagram of the 3-level inverter may be assumed to be composed of six small hexagons.

- These hexagons are focused at the center fn the six high-points or called the apexes of the inner hexagon as shown in Figure. 2. The two steps discussed above should be employed again in order to get the space vector diagram of a 2-level inverter simplified.

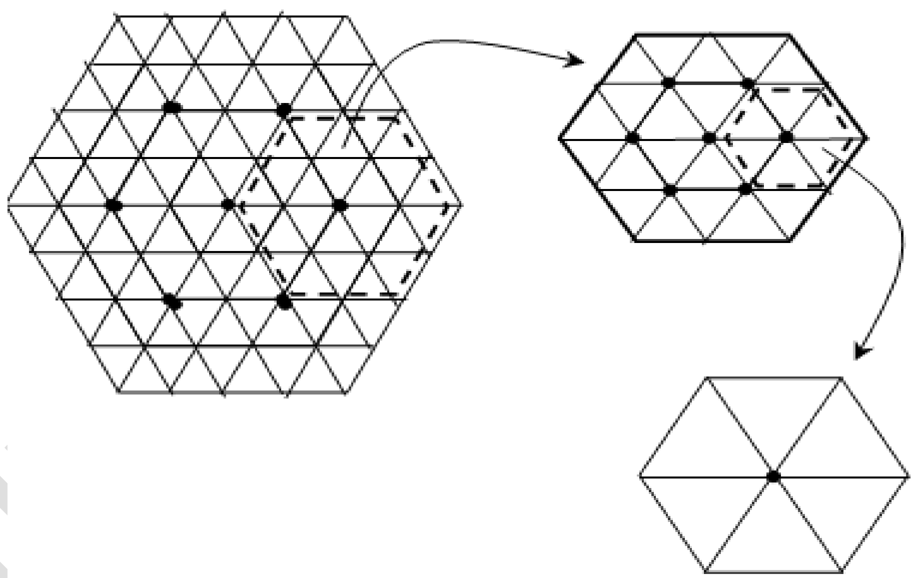


Figure. 2. A 5-level space vector diagram simplified into 2-level space vector diagram

A	B	C	V_a	V_b	V_c	V_{ab}	V_{bc}	V_{ca}
0	0	0	0	0	0	0	0	0
1	0	0	2/3	-1/3	-1/3	1	0	-1
1	1	0	1/3	1/3	-2/3	0	1	-1
0	1	0	-1/3	2/3	-1/3	-1	1	0
0	1	1	-2/3	1/3	1/3	-1	0	1
0	0	1	-1/3	-1/3	2/3	0	-1	1
1	0	1	1/3	-2/3	1/3	1	-1	0
1	1	1	0	0	0	0	0	0

Table. 1. Table showing the on/off states and output of a 3- Phase VSI

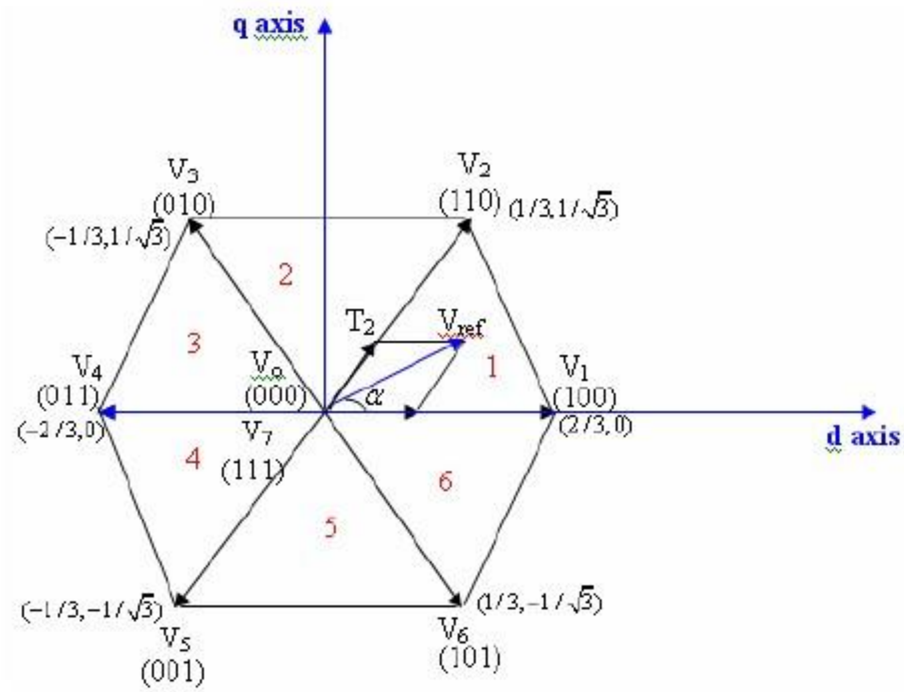


Figure. 3. Switching vectors

The gate pulses generated by SVPWM technique serve the following objectives :

- Linear modulation is extended to a wide range.
- Switching losses are reduced.
- Total harmonic distortion gets reduced in the switching waveform spectrum.
- Implementation is quite easy along with reduces computational calculations.

CHAPTER 3

ACTIVE POWER FILTER

Harmonics in power systems can be curbed with the implementation of two major approaches - passive and active filters. These filters find wide applications in the mitigation of harmonics. As nonlinear loads increase in the power system, requirement of filters also gets increased.

Two types of filters are used for the suppression of harmonic distortion :

- Passive Filters
- **Active Filters**

Capacitors find frequently applications in active and passive filters for the mitigation of harmonics. With a view to safeguard the power system using the means of limiting harmonic currents to move into it by providing a low impedance path, passive filters are used. Passive filters are constituted with the help of capacitors, inductors and resistors. Special equipments employing power-electronic converters to counteract current and voltage harmonics generated by nonlinear loads are nothing but active filters. They mostly find applications in distribution networks for sagging in voltage, flickering, where there are harmonics in current and voltages, etc. Using the filter would result into a better quality of power.

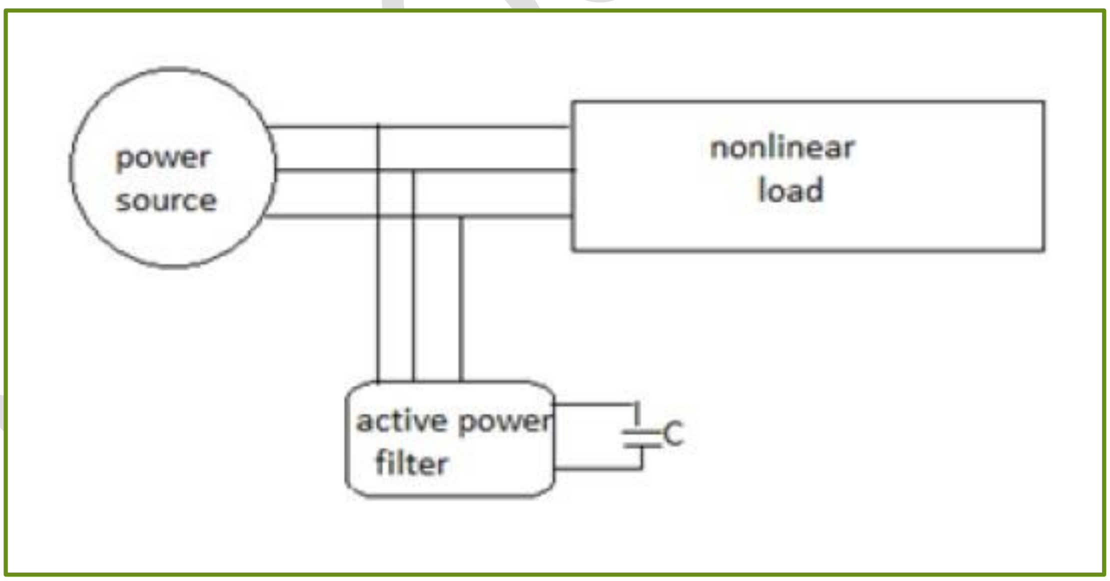


Figure. 4. Block Diagram of active filters

Power quality problems are well improved with the flexibility and versatility of active filters to mitigate harmonic currents and voltage in the power system. The compensated voltage cancels out the voltage harmonics produced in the load.

Shunt Active Power Filter (APF) mainly aims at generating compensating currents and feed as inverter output in order to cancel out the current harmonics present in the induction motor. It thus results in sinusoidal output without harmonics.

Operating Principle of Active Power Filter :

- First, load current is sensed and then the harmonic current signal is extracted in order to eliminate current harmonics.

- A reference signal is generated with the help of harmonic current signal and reactive current signal in order to regulate the current source which is present at the point of common connection of source and load.

- Finally, it results in the supply of real power only from the mains and reactive and harmonic power from the active filter.

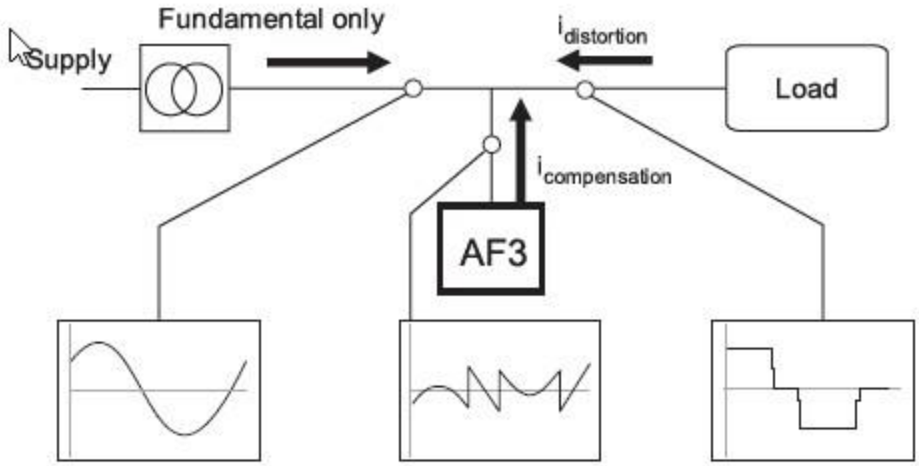


Figure. 5. Input current waveform of a 6-pulse rectifier

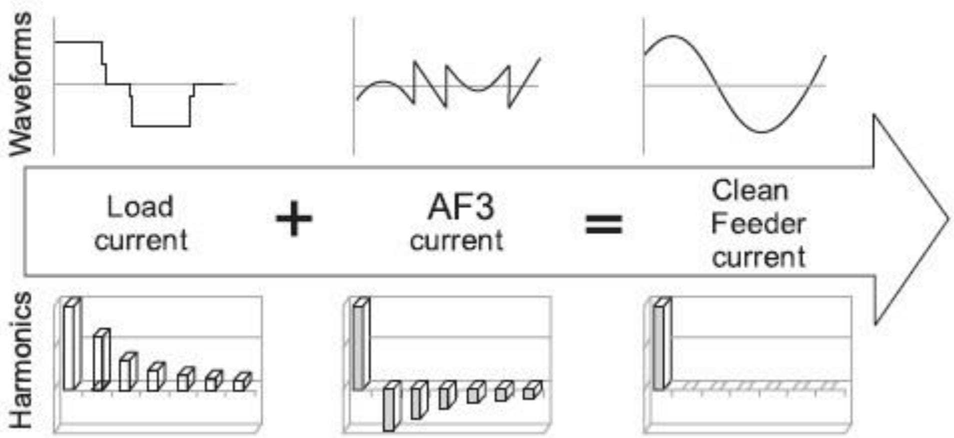


Figure. 6. Improvised waveform with the presence of AF3 in shunt

Usually two types of active filters exist :

- Shunt filters and
- Series filters.

Advantages of Active Filter over Passive Filter :

- One of the great advantages of using an active filter over the passive filter is that it can be used to reduce the effects of harmonics of more than one order.
- Active filters are also useful in flickering problems that are caused in the power system.

Disadvantages of Active Filter over Passive Filter :

- Active filters cost more than the passive filters.
- Active filters cannot be used for small loads in a power system.
- Because of the existence of harmonics in both current and voltage, active filter may fail to resolve the issue in certain typical applications.

SHUNT ACTIVE POWER FILTER

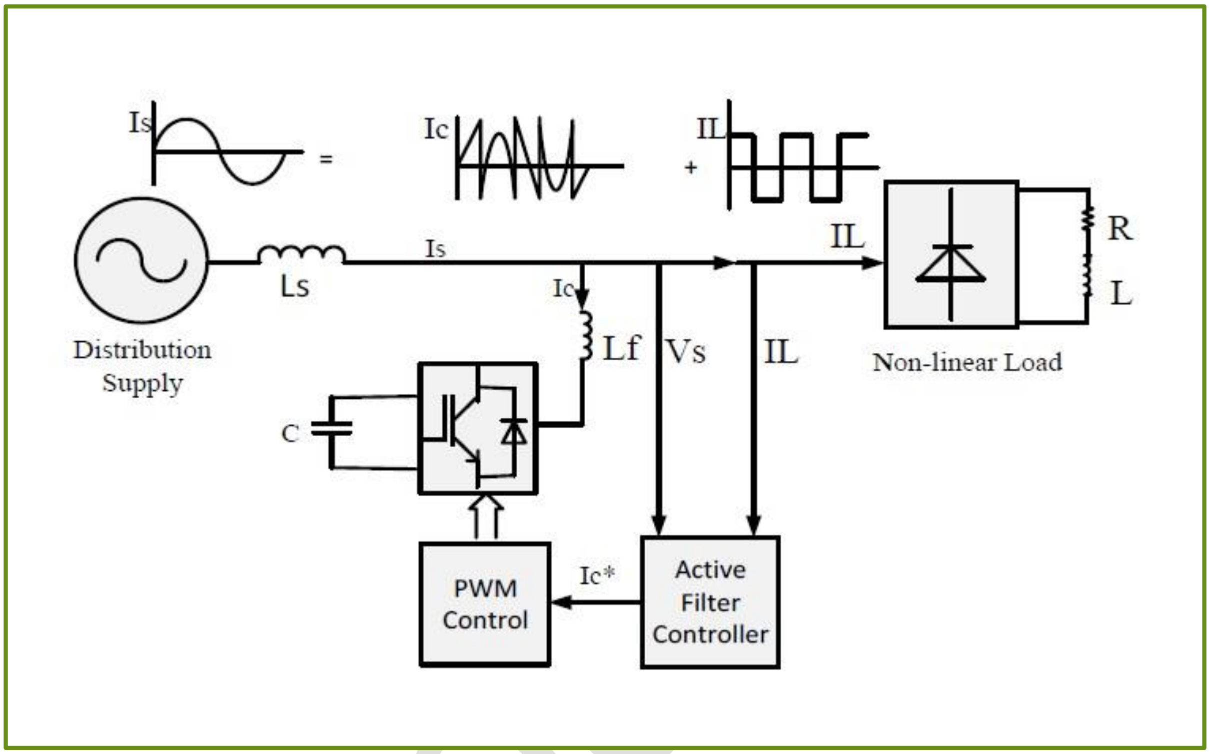


Figure. 7. Basic configuration of a shunt active filter

- This device is connected in parallel.
- Shunt Active Filter helps in the compensation of current harmonics as well as in reactive power compensation.
- It also holds good for the improvisation of power factor in turn increasing efficiency by mitigating the losses caused by harmonics.
- As a consequence, the total current drawn from the AC mains takes the form of a sine wave, in this manner reducing harmonics to a maximum extent.

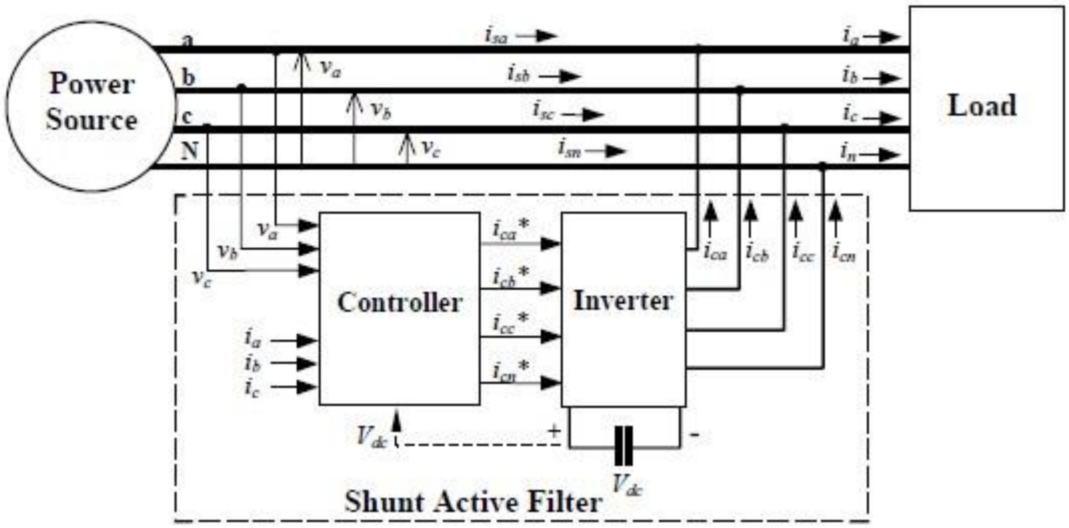


Figure. 8. Shunt active filter in a 3-phase power system

✓ WORKING PRINCIPLE

- The compensating current is generated by a current-controlled VSI.
- The operation of shunt active filter is such that it eliminates current harmonics by supplying a current of equal magnitude and opposite polarity. This in turn results in terminating the harmonic components drawn by the nonlinear load and maintaining the supply current waveform sinusoidal in nature. Consequently, it mitigates the harmonics.

✓ Components of Shunt Active Filter

1. DC Link Capacitor

It performs the following major functions :

- Keeps a constant non-varying DC voltage.
- Provides the difference of real power between the load and source at transient condition and stores it.

2. PI Controller

- PI controller used is discrete in nature.
- The reference voltage and actual voltage are taken as inputs and output provided by it is the maximum value of the reference current which depends on the error got from the difference between the reference and the actual quantities.
- The steady state error in DC component is eliminated.

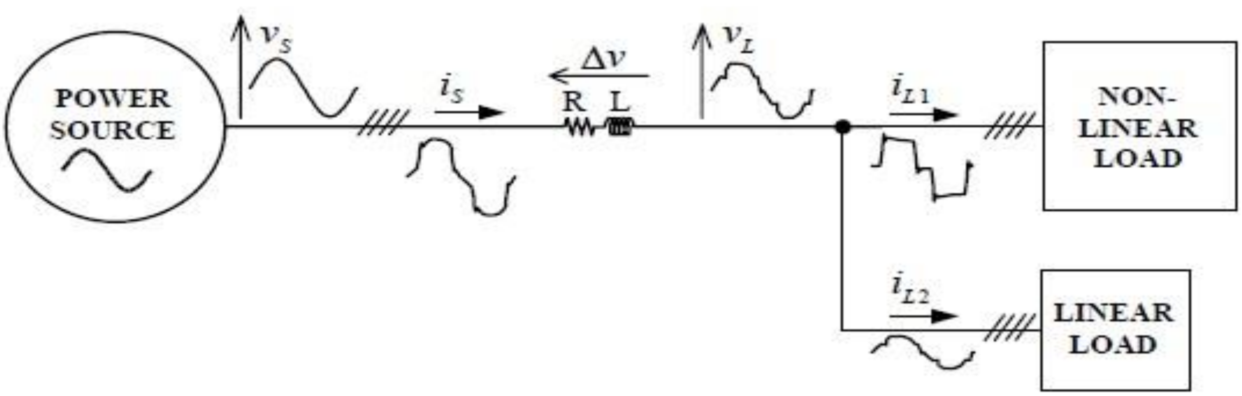


Figure. 9. Non-linear load in the power system

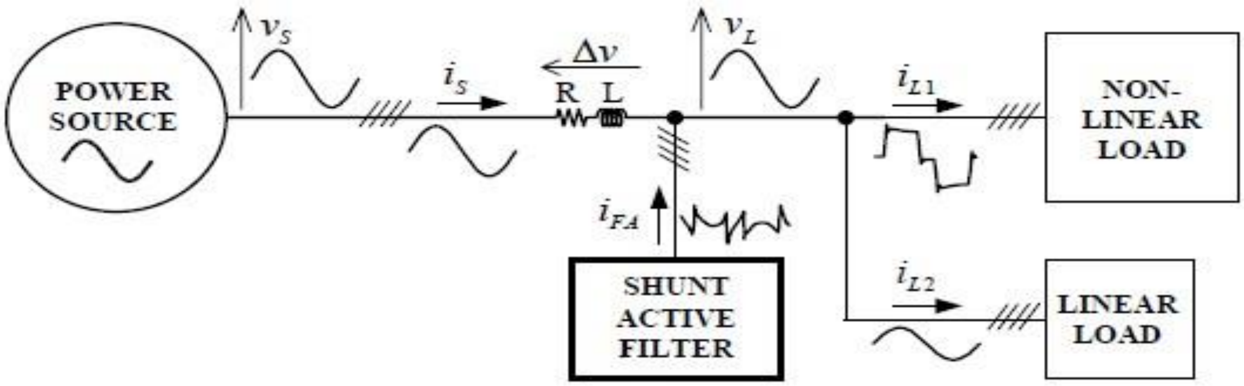


Figure. 10. Non-linear load along with a shunt active filter in power system

✓ CONTROL METHODS FOR ACTIVE FILTERS

- In attaining the objectives of compensation, in determining filter power rate and judging the dynamic and steady-state performance of an active filter, control methods need to be thoroughly revised.
- Actually, there are various approaches concerning the calculation of the compensation currents and voltages from the available measured distorted quantities. These approaches can be classified as: **frequency-domain and time-domain.**
- The first approach, i.e. frequency-domain approach advocates the utilization of Fourier transform and Fourier analysis. This may lead to a huge amount of calculations, leaving the control method heavy and troublesome.
- In the second approach, i.e. time-domain approach, the conventional notions of circuit analysis as well as algebraic transformations have been considered in order to simplify the control strategy.

CHAPTER 4

MATLAB SIMULATIONS AND RESULTS

1.

1.1 Simulink Diagram of VSI

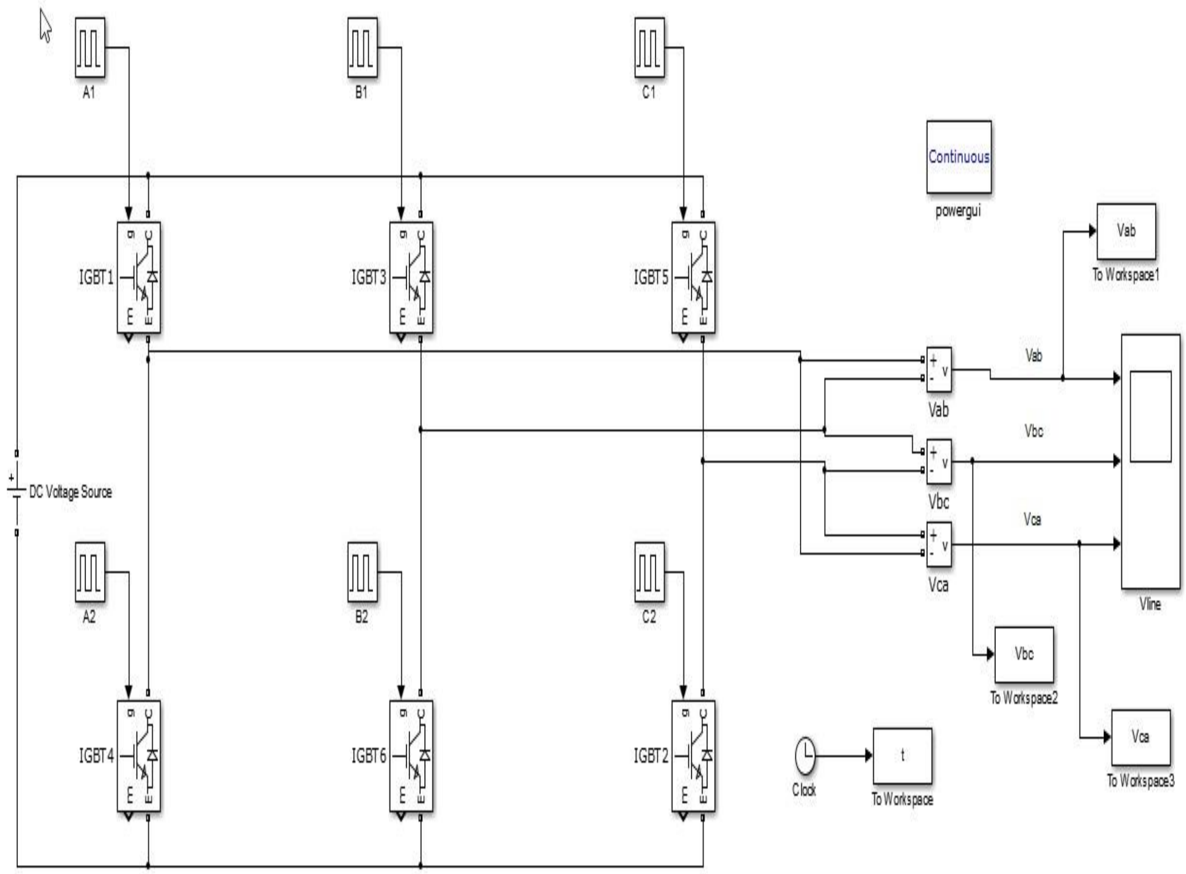


Figure. 11. Simulink Model of Voltage Source Inverter (VSI)

1.2 Output

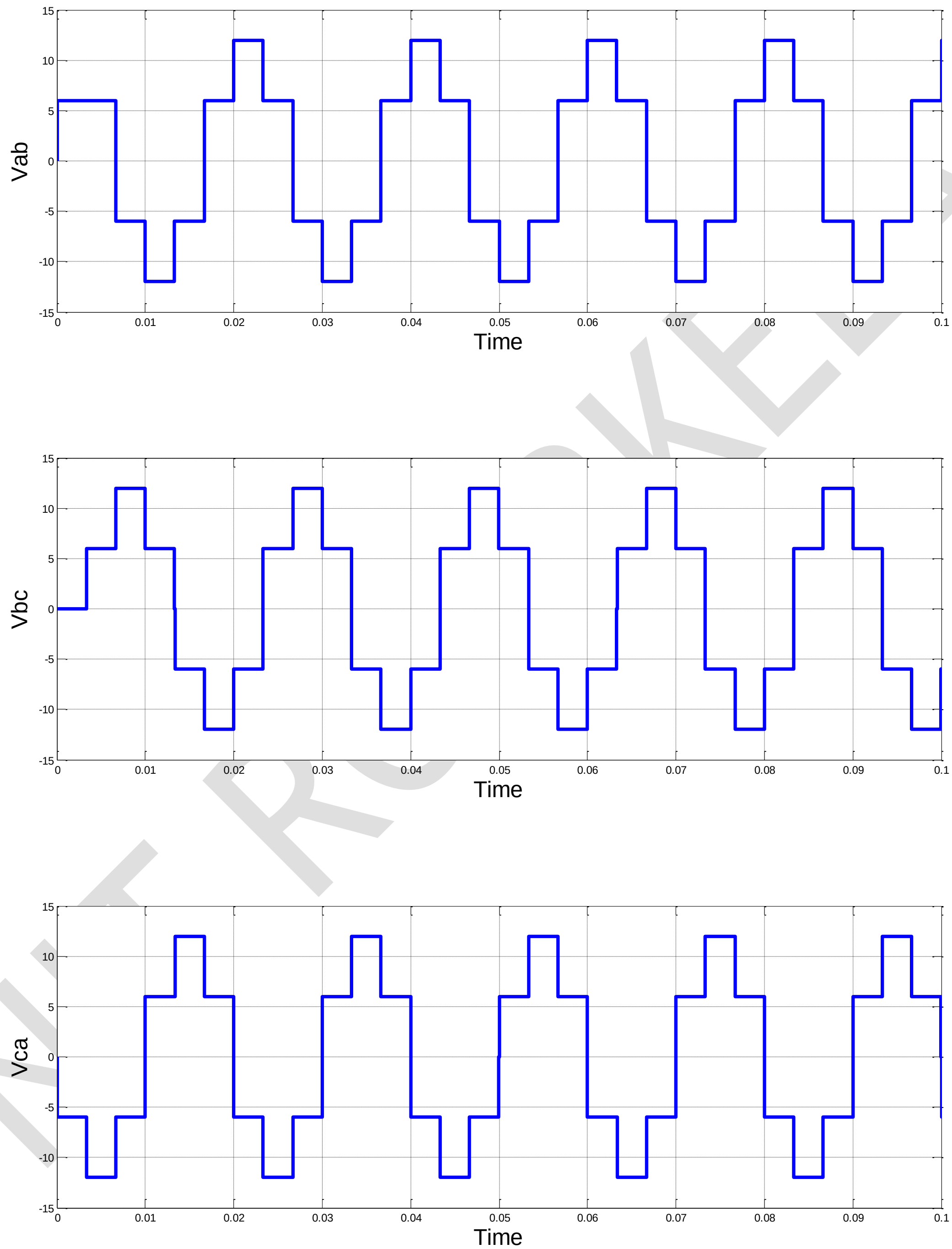
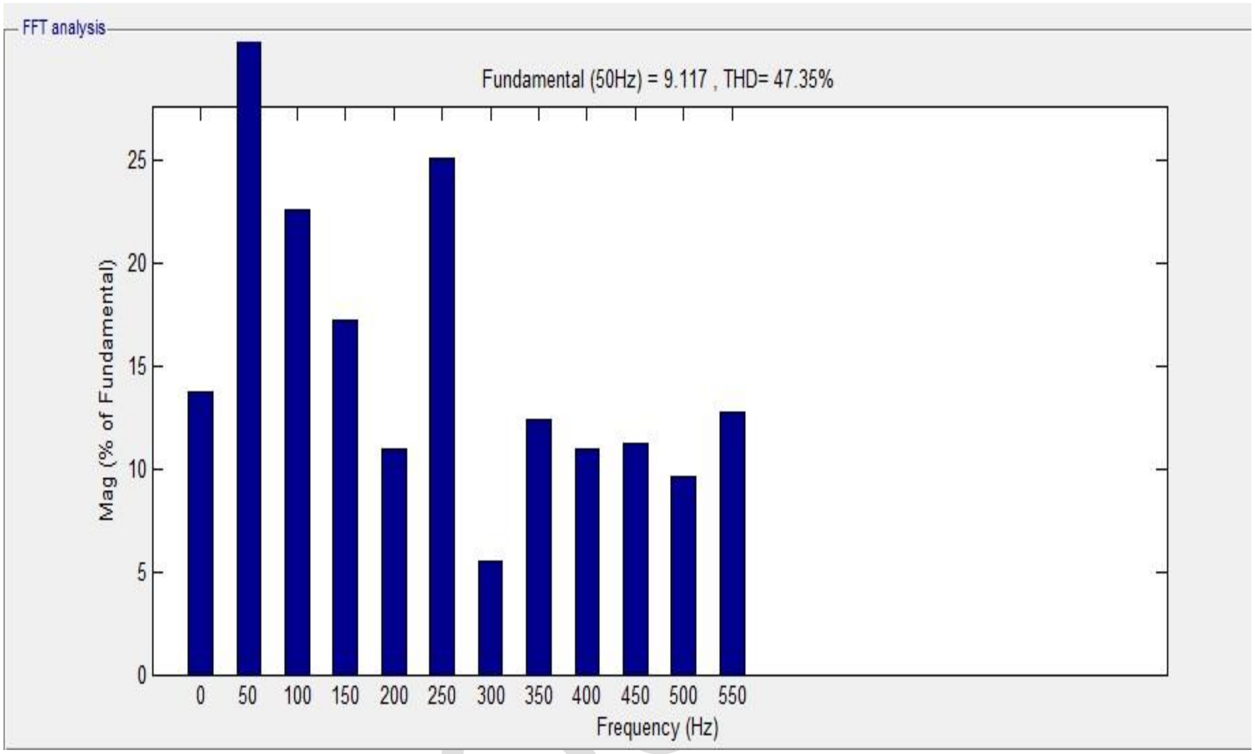


Figure. 12. Output for voltage source inverter (VSI)

1.3 Total Harmonic Distortion (THD)



FFT analysis

```
Sampling time     = 0.000834028 s
Samples per cycle = 24
DC component      = 1.25
Fundamental       = 9.117 peak (6.446 rms)
THD               = 47.35%

      0 Hz  (DC):          13.71%    270.0°
     50 Hz  (Fnd):        100.00%     66.3°
    100 Hz  (h2):          22.57%    234.9°
    150 Hz  (h3):          17.19%    219.6°
    200 Hz  (h4):          10.97%    210.0°
    250 Hz  (h5):          25.14%    -34.1°
    300 Hz  (h6):           5.48%    270.0°
    350 Hz  (h7):          12.39%    122.2°
    400 Hz  (h8):          10.97%    270.0°
    450 Hz  (h9):          11.20%    258.3°
    500 Hz (h10):           9.61%    248.8°
    550 Hz (h11):          12.78%     -0.9°
```

Figure. 13. Total Harmonic Distortion in the induction motor without using filter

2.

2.1 Speed control of induction motor using Space Vector Pulse Width Modulation (SVPWM)

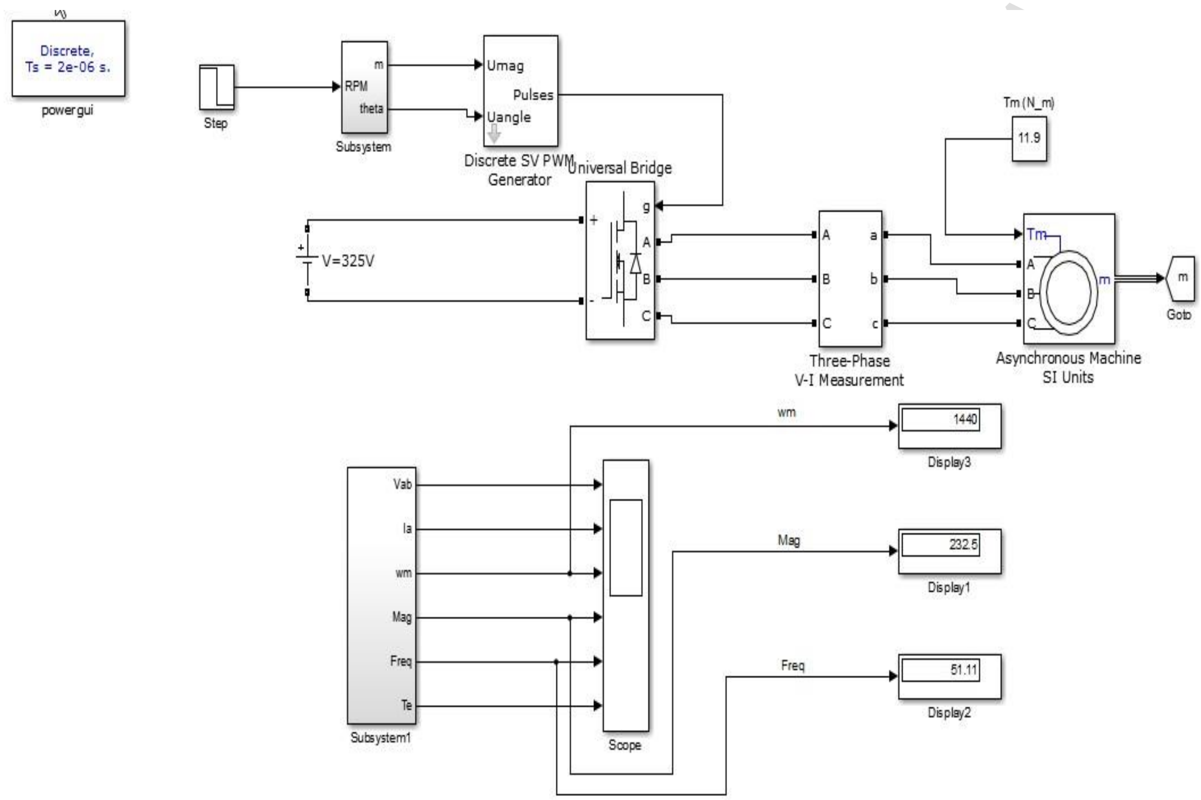


Figure. 14. SVPWM fed induction motor

2.2 Output

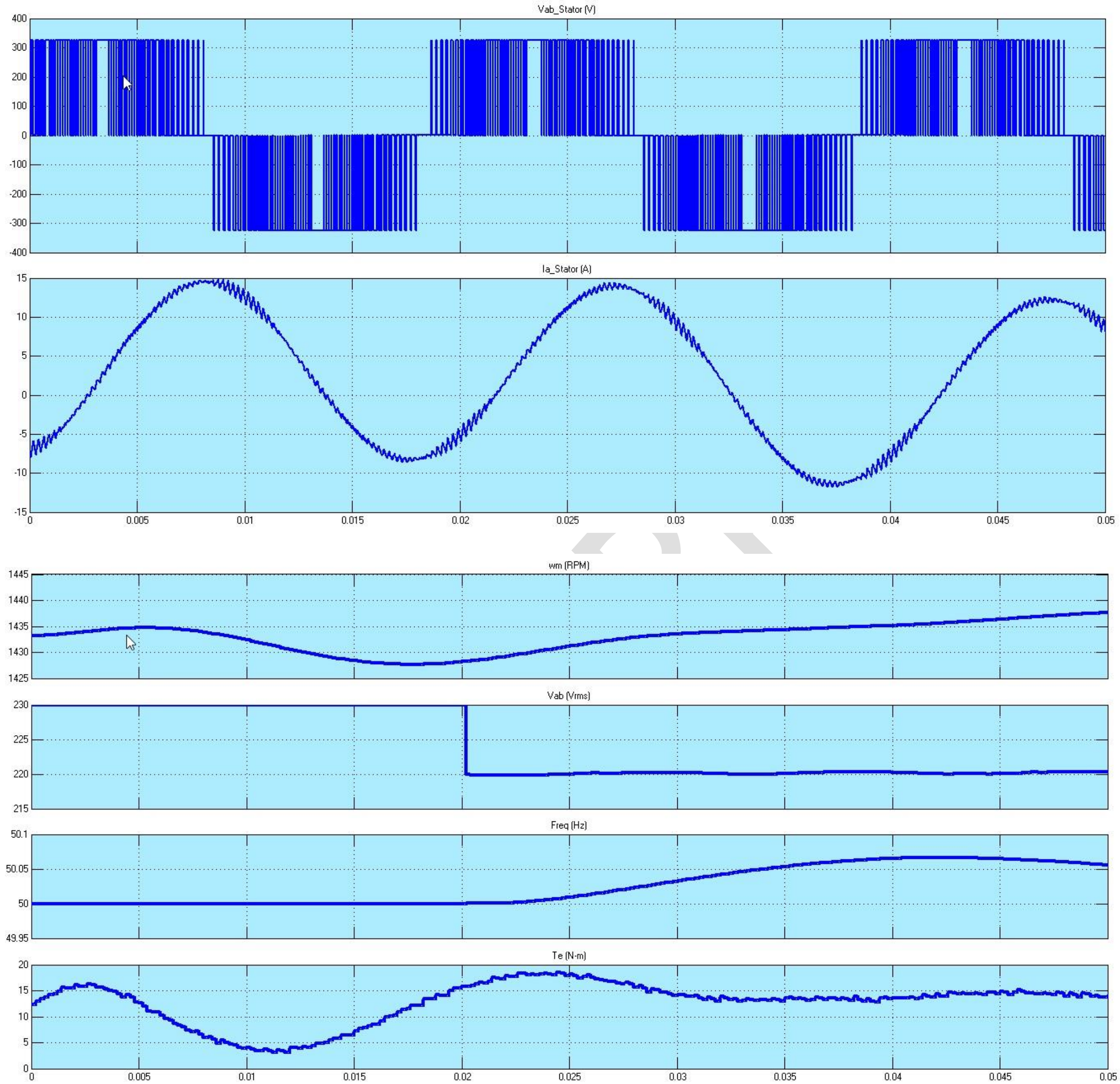


Figure. 15. Output waveforms for SVPWM case

2.3 FFT ANALYSIS FOR THD

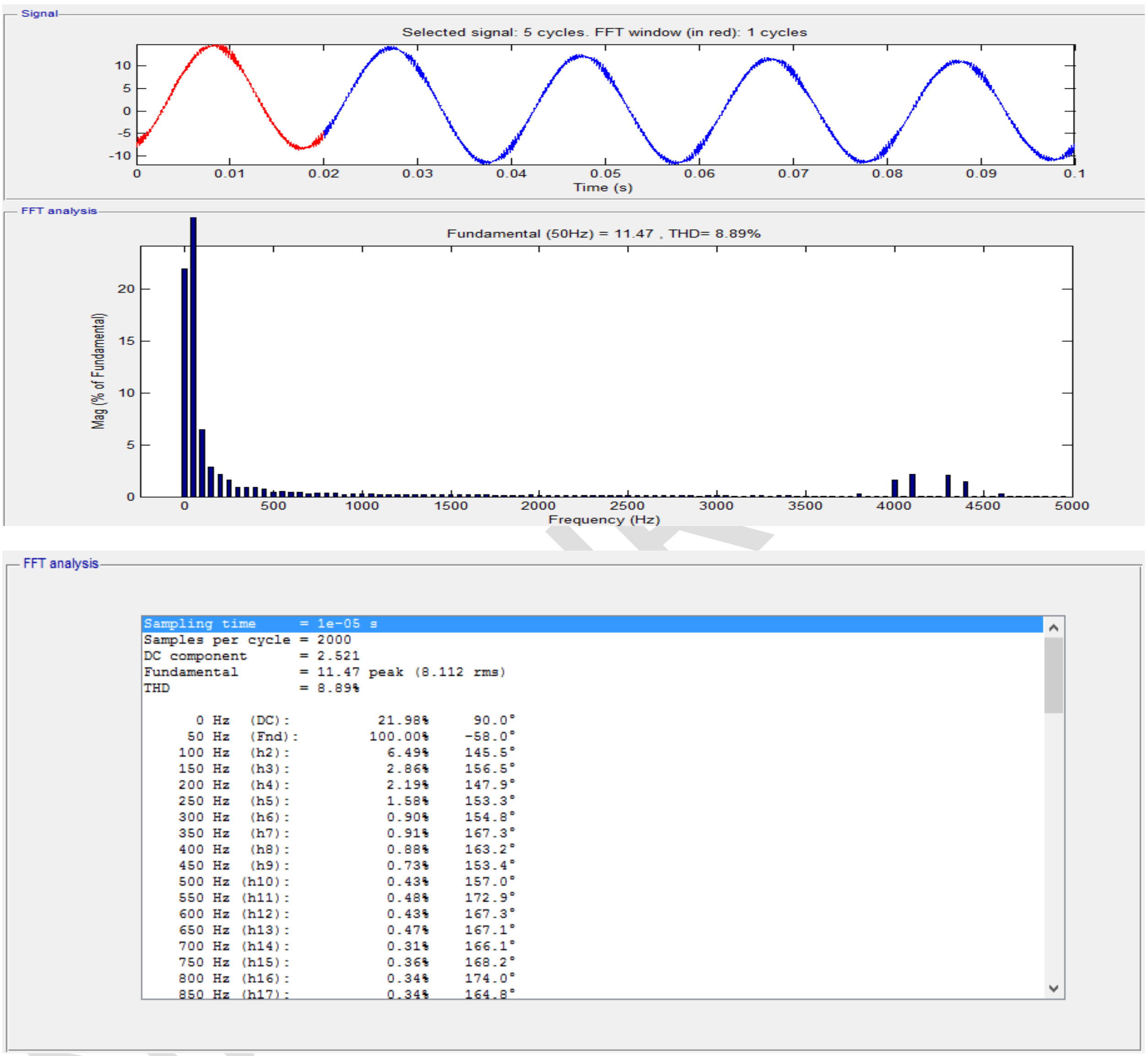


Figure. 16. THD in output current waveform after SVPWM

3.

3.1 Speed Control of Induction Motor using shunt active filter

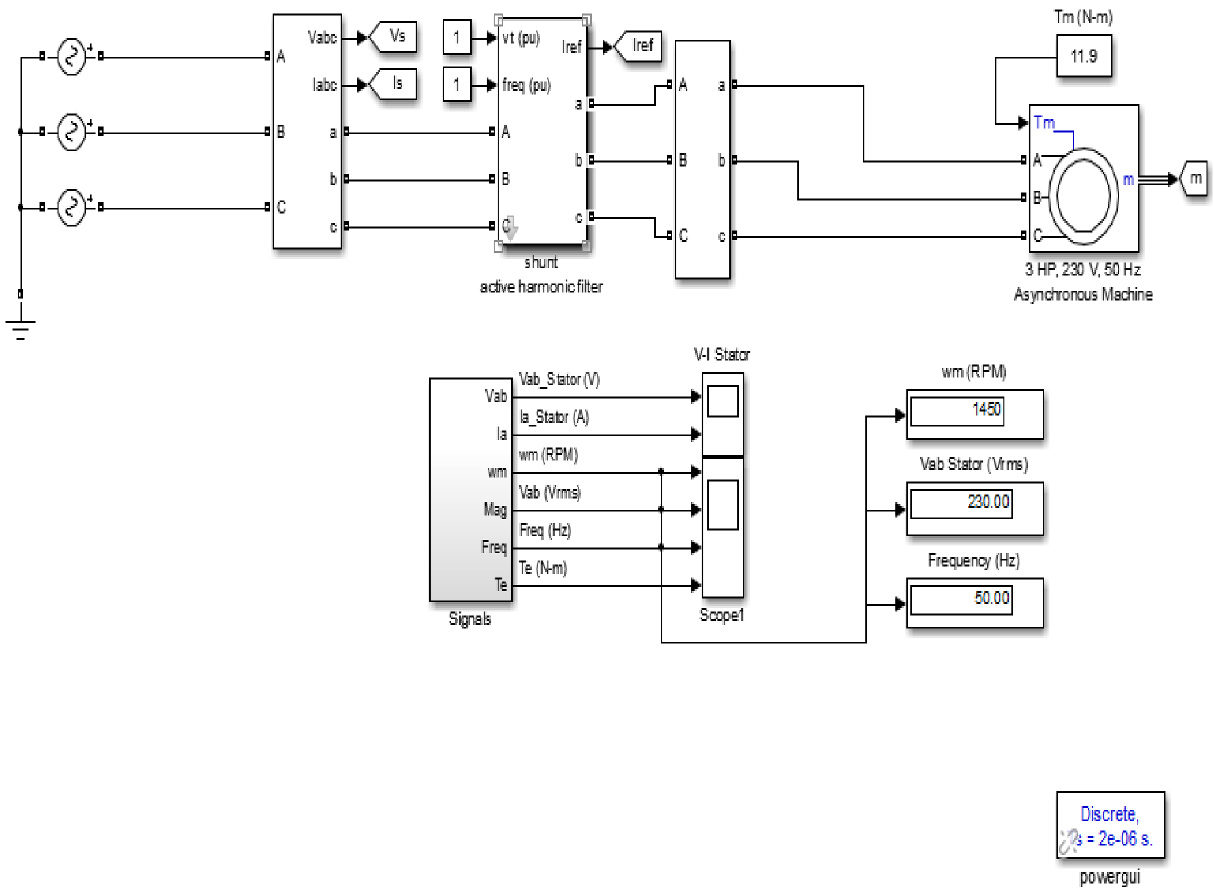


Figure. 17. Speed control of induction motor using shunt active filter

3.2 Output

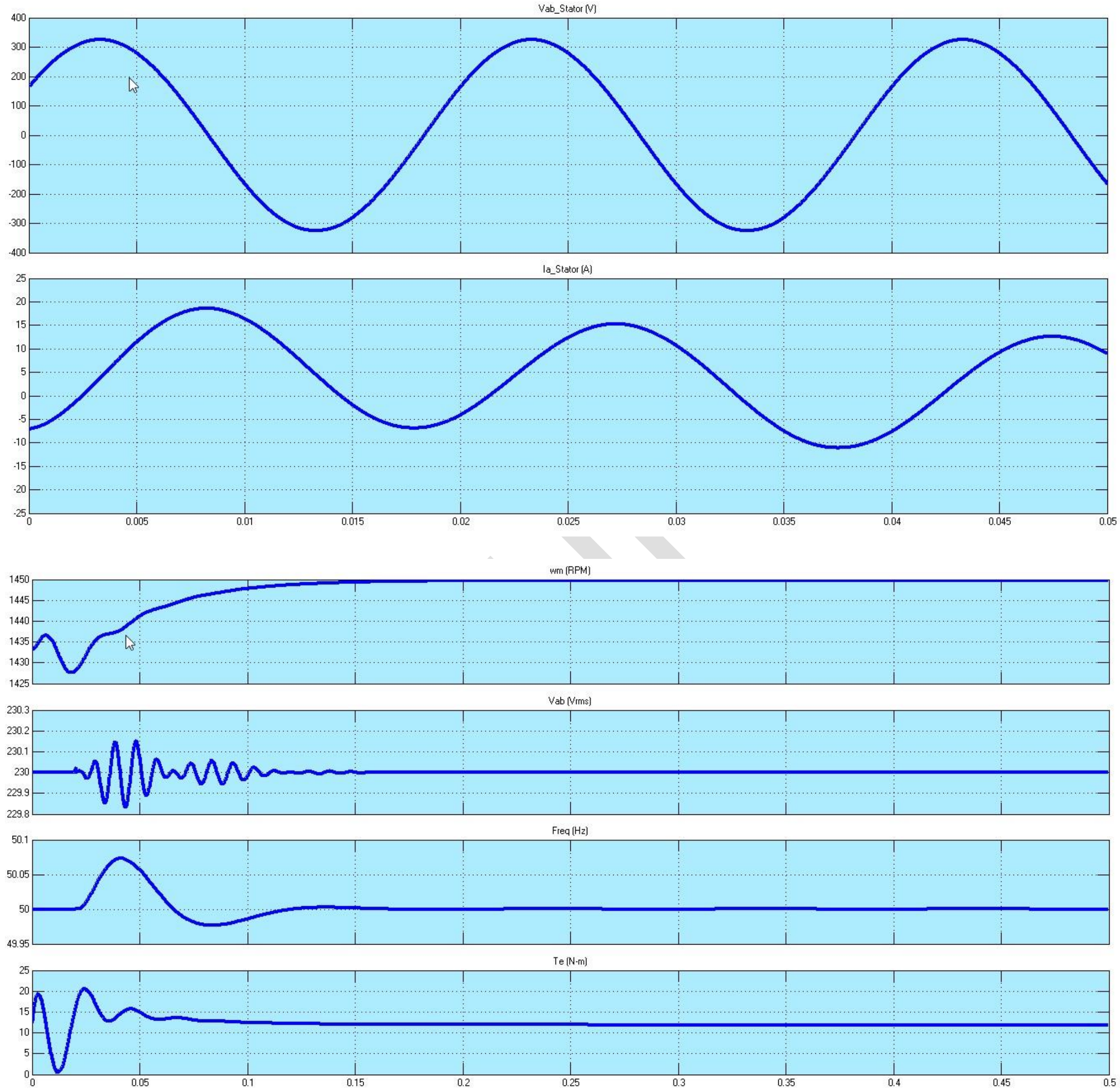


Figure. 18. Output waveforms for shunt active filter case

3.3 FFT ANALYSIS FOR THD

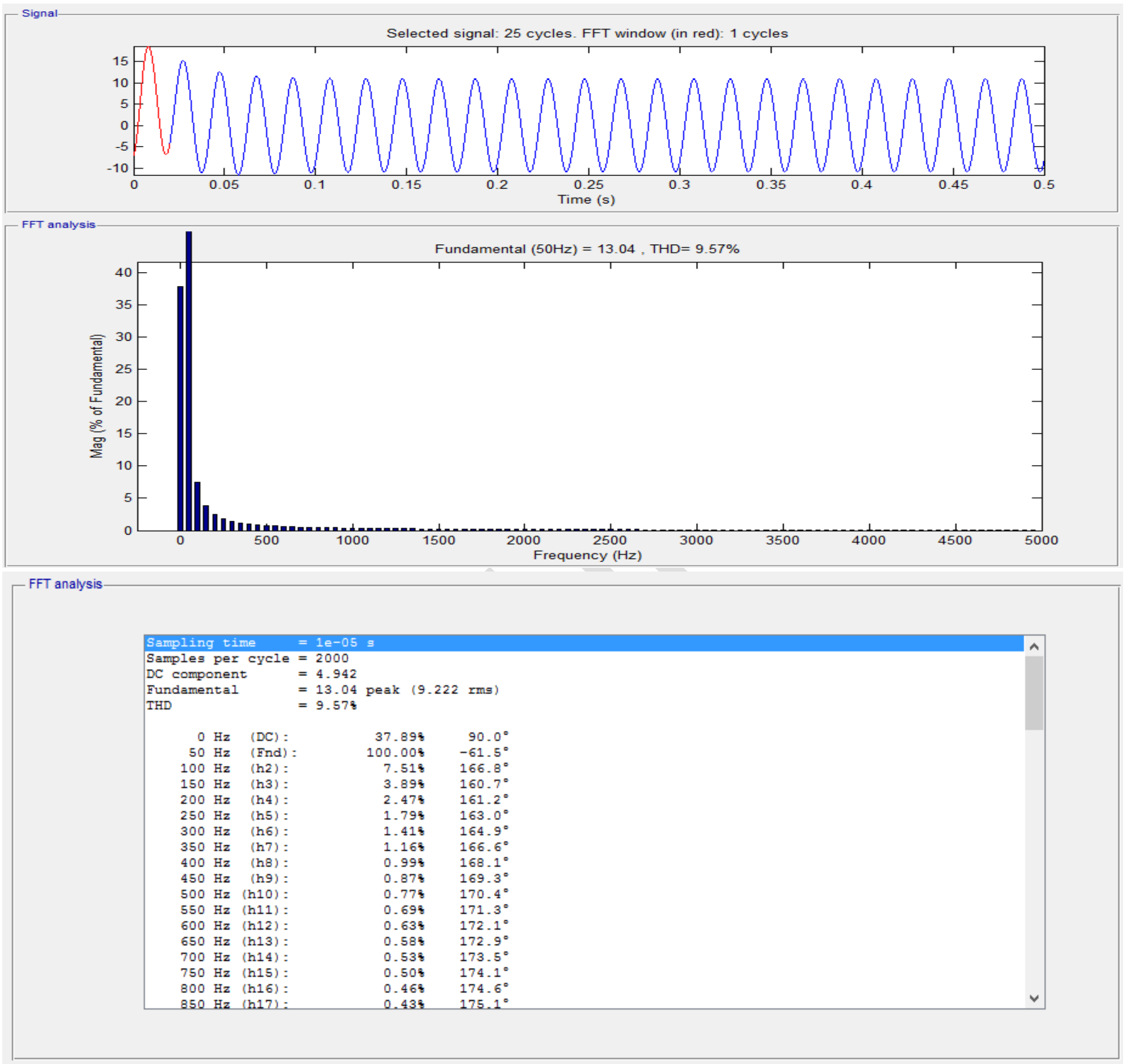


Figure. 19. THD in output current waveform with shunt active filter

CHAPTER 5

COMPARATIVE ANALYSIS

Harmonic order	Harmonic Factor (in %)		
	Without Filter	With Filter	
		Shunt Active Filter	SVPWM
2^{nd} Harmonic	22.57	7.51	6.49
3^{rd} Harmonic	17.19	3.89	2.86
4^{th} Harmonic	10.97	2.47	2.19
5^{th} Harmonic	25.14	1.79	1.58
6^{th} Harmonic	05.48	1.41	0.90
7^{th} Harmonic	12.39	1.16	0.91
8^{th} Harmonic	10.97	0.99	0.88
9^{th} Harmonic	11.20	0.87	0.73
10^{th} Harmonic	09.61	0.77	0.43
11^{th} Harmonic	12.78	0.69	0.48

Table. 2. Comparative study of harmonic factor in the system

THD CALCULATIONS:

A) Without Filter

$$THD = (22.57^2 + 17.19^2 + 10.97^2 + 25.14^2 + 5.48^2 + 12.39^2 + 10.97^2 + 11.20^2 + 9.61^2 + 12.78^2)^{1/2}$$

$$= 47.35\ \%$$

B) With Filter

i) Shunt Active Filter Method

$$THD = (7.51^2 + 3.89^2 + 2.47^2 + 1.79^2 + 1.41^2 + 1.16^2 + 0.99^2 + 0.87^2 + 0.77^2 + 0.69^2)^{1/2}$$

$$= 9.57\ \%$$

ii) Space Vector PWM Method

$$THD = (6.49^2 + 2.86^2 + 2.19^2 + 1.58^2 + 0.90^2 + 0.91^2 + 0.88^2 + 0.73^2 + 0.43^2 + 0.48^2)^{1/2}$$

$$= 8.89\ \%$$

CHAPTER 6

CONCLUSION

In this project, we studied harmonics, its causes, its effects and influences on the power system. Then, we took an overview of the methods for harmonic reduction.

The harmonics elimination techniques we adopted are-

- Shunt Active Filter
- SVPWM

Then we underwent MATLAB simulation.

First, we simulated voltage source inverter (VSI) without any filtration technique to estimate the actual harmonic content.

Then, we simulated the VSI fed induction motor with harmonics reduction schemes and did FFT analysis to estimate %THD.

The total harmonic distortion we got with shunt active filter is 9.57 % and 8.89 % with the implementation of SVPWM.

Here, we can see that % THD is less in case of SVPWM as compare to shunt active filter.

Hence, we can easily conclude that Space Vector Pulse Width Modulation Technique is more efficient in eliminating harmonics.

CHAPTER 7

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